CRIS Collaboration meeting 2025, Leuven
30/1 - 2025

# Future francium plans
(suggestion)

*"The future belongs to those who prepare for it today"*

*Anders Kastberg , Pierre Lassegues*

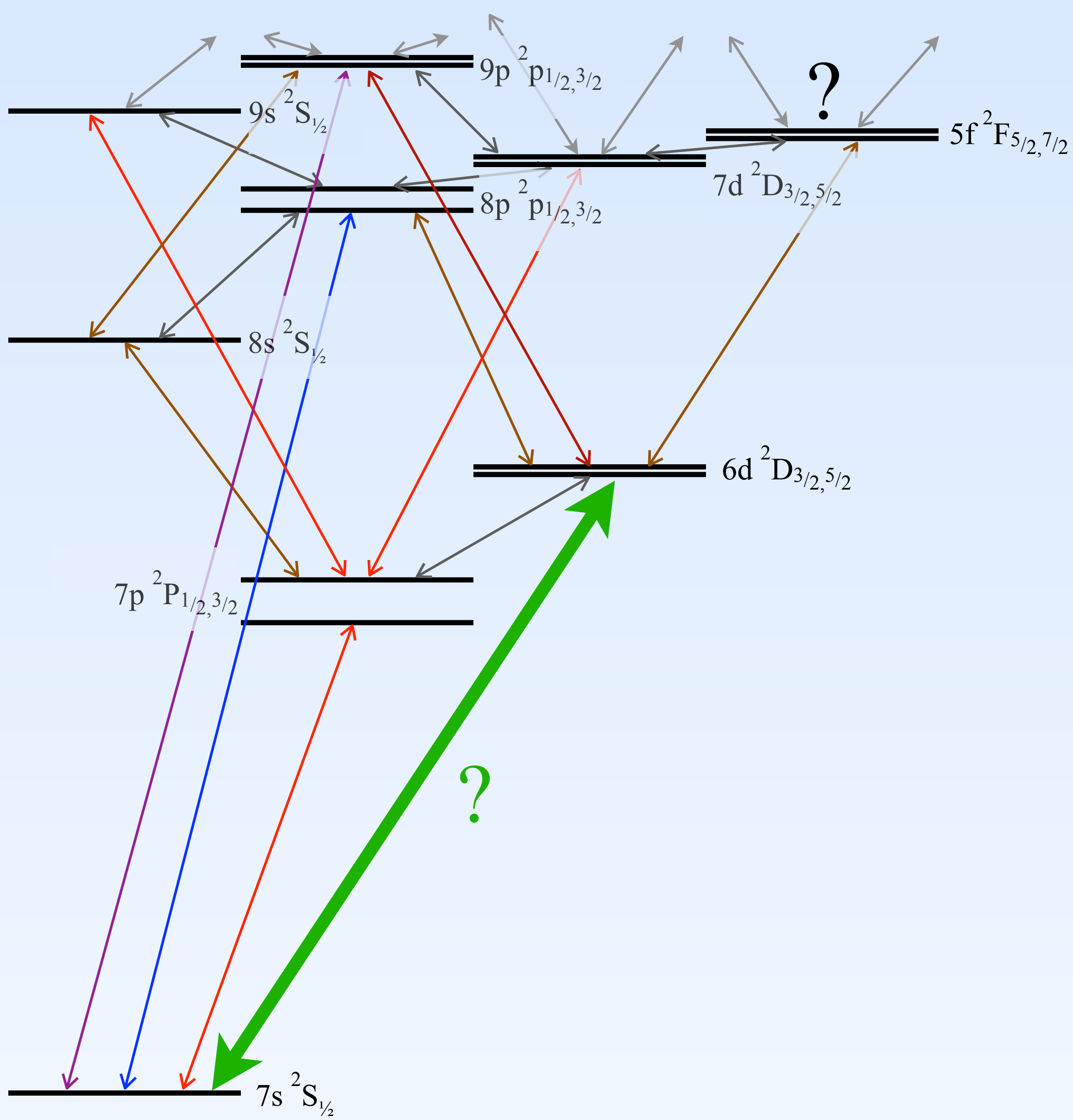
UNIVERSITÉ CÔTE D'AZUR

CRIS

# What I will NOT talk about:

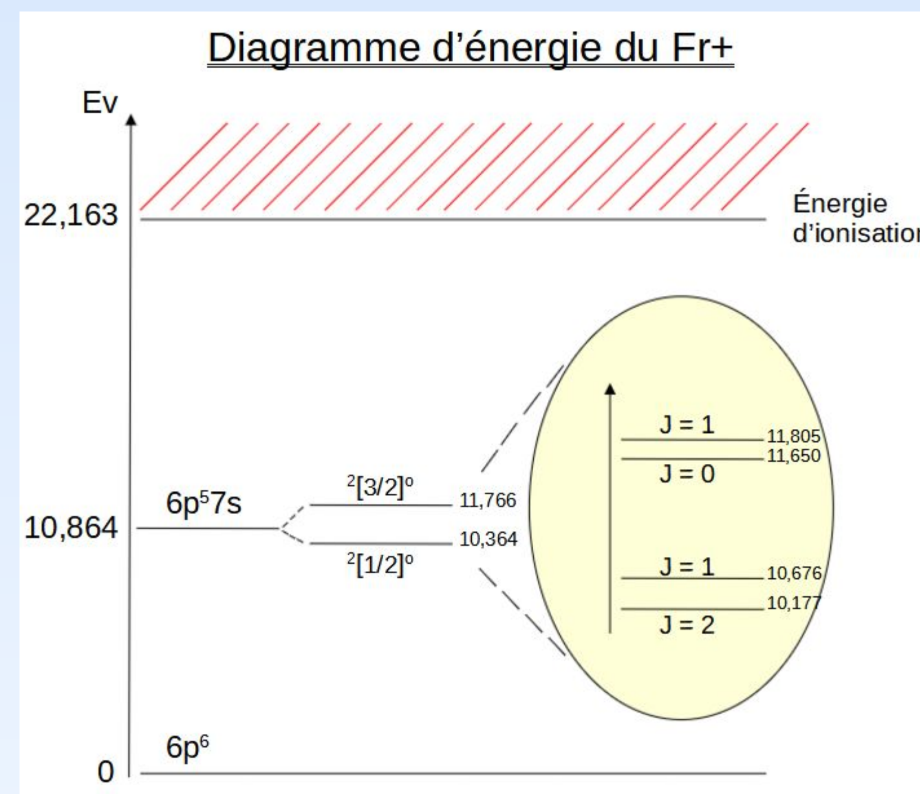
## There still loads unexplored stuff in Fr

*energy levels, lifetimes, hfs, isotope shifts …*




## Francium plus

| Configuration | Term | J | Level (eV) | Uncertainty (eV) | Reference |
|---|---|---|---|---|---|
| $6p^6$ | $^1S$ | 0 | 0.0000 | | L16139 |
| Fr III ($6p^5$ $^2P°_{3/2}$) | Limit | --- | [22.4] | 1.9 | L16139 |

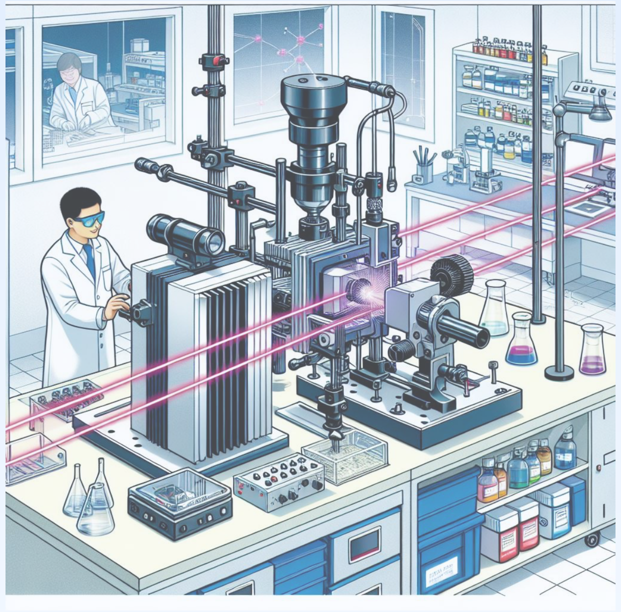



*I do have ideas also about measurements on $Fr^+$*

# This suggestion has two, equally important, aspects

- Fundamental science: hyperfine anomaly, Bohr-Weisskopf effect, extended study of IS and HFS

- Methodological advancement: two-photon doppler-free spectroscopy on a (radioactive) ion beam



# Bohr-Weisskopf

Hyperfine anomaly

$H = a\, \mathbf{I} \cdot \mathbf{J}$

Extended nucleus $\Rightarrow a_{\text{point}}$
modified by two effects

1. Extended charge distribution:
   *Breit-Rosenthal*
2. Extended and distributed nuclear magnetization: *Bohr-Weisskopf*

$a = a_{\text{point}}\,(1 + \varepsilon_{\text{BW}})(1 + \varepsilon_{\text{BR}})$

If two isotopes are compared:

$$\frac{a_1}{a_2} \approx \frac{g_I(1)}{g_I(2)}\,[1 + \Delta^2_{\text{BW}}]$$

$$\Delta^2_{\text{BW}} \equiv \varepsilon_{\text{BW}}(1) - \varepsilon_{\text{BW}}(2) \qquad g_I = \frac{\mu_I}{I}$$

independent measurements needed:

1. nuclear gyromagnetic ratio
2. hfs interaction constants

both with accuracies $\approx 10^{-4}$

# BW has a history at ISOLDE

Hyperfine Interactions 74(1992)59–66 59

**SYSTEMATIC MEASUREMENTS OF THE BOHR–WEISSKOPF EFFECT AT ISOLDE**

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*But the project died out (retirements, bad luck, karma ....)*

# The Jonas table …

Atomic Data and Nuclear Data Tables 154 (2023) 101589

Contents lists available at ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

## Table of hyperfine anomaly in atomic systems — 2023

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A R T I C L E I N F O

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A B S T R A C T

This table is an updated compilation of experimental values of the magnetic hyperfine anomaly in atomic and ionic systems. The literature search covers the period up to December 2022. A short discussion on general trends of the hyperfine anomaly and the theoretical developments is included.



*Excellent compilation of existing data*

# The Jonas table …

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Br | 79 | 3/2 | 81 | 3/2 | 4p$^5$ $^2P_{3/2}$ | −0.00003(4) | [37][77] |
| Rb | 85 | 5/2 | 84 | 2 | 5s $^2S_{1/2}$, s-anomaly | −1.7(1.0) | [23] |
| | 85 | 5/2 | 86 | 2 | 5s $^2S_{1/2}$, s-anomaly | 0.17(9) | [35] |
| | 85 | 5/2 | 87 | 3/2 | 5s $^2S_{1/2}$, s-anomaly | 0.35141(2) | [25] |
| | | | | | 6s $^2S_{1/2}$, s-anomaly | 0.361(19) | [25][65][66] |
| | | | | | 7s $^2S_{1/2}$, s-anomaly | 0.342(3) | [25] |
| | | | | | 5p $^2P_{1/2}$ | 0.55(8) | [25] |
| | | | | | 5p $^2P_{3/2}$ | 0.168(5) | [25] |
| | | | | | 6p $^2P_{1/2}$ | 0.31(7) | [25] |
| | | | | | 6p $^2P_{3/2}$ | 0.46(5) | [25] |
| | | | | | 4d $^2D_{3/2}$ | 0.347(4) | [81] |
| | | | | | 4d $^2D_{5/2}$ | 0.41(9) | [97] |
| | | | | | 4d $^2D_{5/2}$ | 0.60(15) | [25] |
| | | | | | 5d $^2D_{3/2}$ | 0.279(6) | [25] |
| | | | | | 5d $^2D_{5/2}$ | 0.44(5) | [25] |
| Mo | 95 | 5/2 | 97 | 5/2 | 4d$^5$5s $^7S_3$ | −0.0101(2) | [41] |

Rb: three pairs of isotopes, d-states also measured

# The Jonas table …

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Xe | 129 | 1/2 | 131 | 3/2 | 6s $^2S_{1/2}$, s-anomaly | 0.0440(44) | [61] |
| Cs | 133 | 7/2 | 131 | 5/2 | $5p^5 6s$ $^3P_2$, s-anomaly | 0.45(5) | [100] |
| | 133 | 7/2 | 134 | 4 | 6s $^2S_{1/2}$, s-anomaly | 0.169(30) | [94] |
| | 133 | 7/2 | $134^m$ | 8 | 6s $^2S_{1/2}$, s-anomaly | −1.38(3) | [54] |
| | 133 | 7/2 | 135 | 7/2 | 6s $^2S_{1/2}$, s-anomaly | 0.037(9) | [94] |
| | 133 | 7/2 | 137 | 7/2 | 6s $^2S_{1/2}$, s-anomaly | 0.0018(40) | [94] |
| Ba | 135 | 3/2 | 137 | 3/2 | 5d6s $^3D_1$ | −0.205(7) | [70] |
| | | | | | 5d6s $^3D_2$ | −0.179(22) | [70] |

Cs: very little data …

# The Jonas table …

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 207 | 1/2 | $197^m$ | 13/2 | 6p7s $^3P_1$ - $6p^2$ $^1D_2$ | −1.68(123) | [85] |
| Fr | 212 | 5 | $206^g$ | 3 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | 0.026(30) | [103] |
| | 212 | 5 | $206^m$ | 7 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.058(27) | [103] |
| | 212 | 5 | 207 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.349(29) | [103] |
| | 212 | 5 | 208 | 7 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.014(46) | [103] |
| | 212 | 5 | 208 | 7 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | 0.032(38) | [69] |
| | 212 | 5 | 209 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.368(29) | [103] |
| | 212 | 5 | 209 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.339(31) | [69] |
| | 212 | 5 | 210 | 6 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | 0.009(32) | [103] |
| | 212 | 5 | 210 | 6 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | 0.007(28) | [69] |
| | 212 | 5 | 211 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.334(31) | [103] |
| | 212 | 5 | 211 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.331(34) | [69] |
| | 212 | 5 | 213 | 9/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.328(34) | [103] |
| | 212 | 5 | 221 | 5/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | −0.704(42) | [103] |
| Ra | 211 | 5/2 | 213 | 1/2 | 7s $^2S_{1/2}$ - 7p $^2P_{1/2}$ $(\Delta_s - \Delta_p)$ | 0.6(2) | [24] |

Fr: two papers by Orozco

# What data exist for Fr and Cs?

- Two experimental Fr papers by Orozco (D1-line, MOT)
- Recent theoretical papers by Jacinda Ginges
- Three experimental paper for Cs (1957, 1962, 1965)

# What do I suggest that we do?

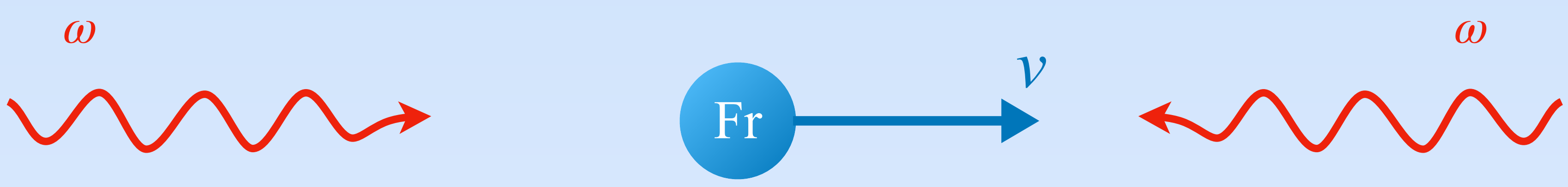
- Extend the data for Fr, more isotopes ……
- Do we know someone that independently measures nuclear moments?
- Study the 7s-6d transition with doppler-free spectroscopy (see slides that will follow)
- And think about also doing it for radioisotopes of Cs

# Are d-states relevant in this context?

- Measurements on Rb shows an anomaly also for d
- There should be polarisation effects
- Is the trend the same for s-d as for s-p?
- If we trust the data for 7s, results on 7s-6d will improve also the understanding of p-states
- Combination of data should improve knowledge of the nuclear structure
- Octupole moments
- Data on 6d needed for analyses of PNC
- Comparison with theory (Ginges, Sahoo)

# Two-photon spectroscopy

Lab frame




Atomic frame


First-order doppler cancelled!

# In an ion beam?

Two-photon spectroscopy have been done many times in cells and also in traps

On ion-beams, I find very little

ELSEVIER

Optics Communications

Volume 16, Issue 2, February 1976, Pages 292-294

## Two-photon spectroscopy in a fast atomic beam ☆

Rainer Salomaa **, Stig Stenholm

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https://doi.org/10.1016/0030-4018(76)90240-6

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Abstract

We suggest the use of a fast atomic beam to obtain resonance enhancement in Doppler-free two-photon spectroscopy. The method requires only one laser frequency thus avoiding the complications due to a residual Doppler shift.

VOLUME 47, NUMBER 21    PHYSICAL REVIEW LETTERS    23 NOVEMBER 1981

**Resonant Two-Photon Spectroscopy in a Fast Accelerated Atomic Beam**

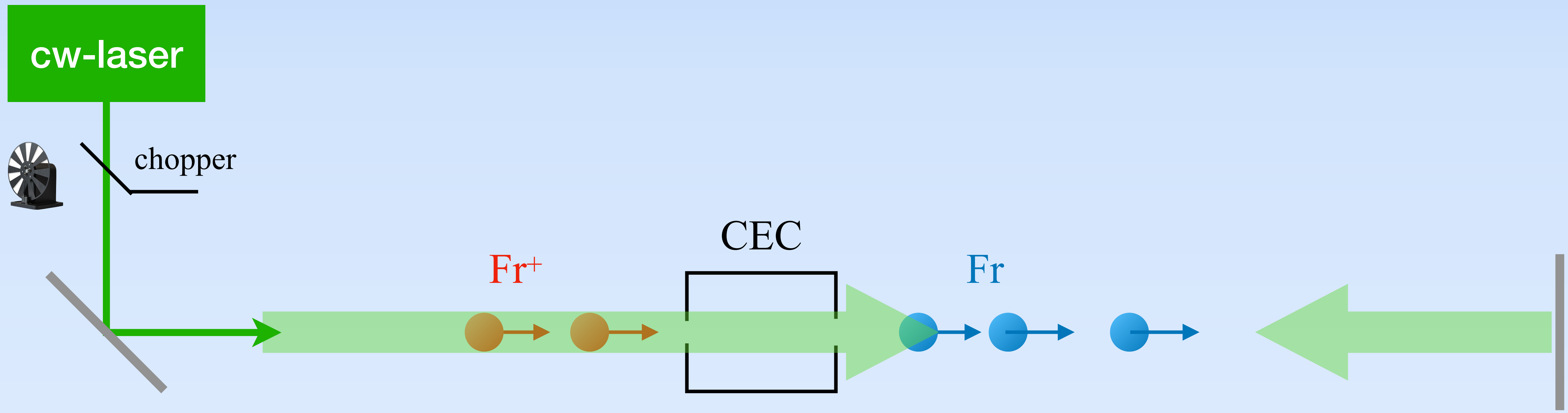
O. Poulsen and N. I. Winstrup

*Institute of Physics, University of Aarhus, DK-8000 Aarhus C, Denmark*

(Received 13 July 1981)

Two-photon spectroscopy has been performed in a fast, accelerated atomic beam, with a resolution limited only by the natural linewidth of the upper excited level. The main feature of the experiment is the "creation" of a completely harmonic three-level atom, by using the relativistic transformation between the laboratory and atom rest frame. Thus resonant two-photon absorption, with a strength comparable to electric-dipole transitions, takes place. The systematic effects of importance in spectroscopy are investigated.

# What would a CRIS experiment look like?

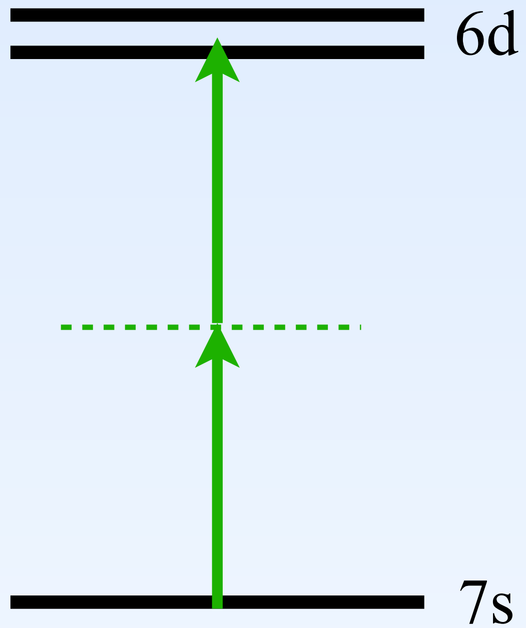



Narrow bandwidth cw-lasers, several isotopes

Fr 7s-6d ; 1232 nm   and   1217 nm

Fr 6s-5d ; 1384 nm   and   1370 nm

eg. tailor made ECDLs (add partner for lasers?)




*6d HFS should be well resolved*

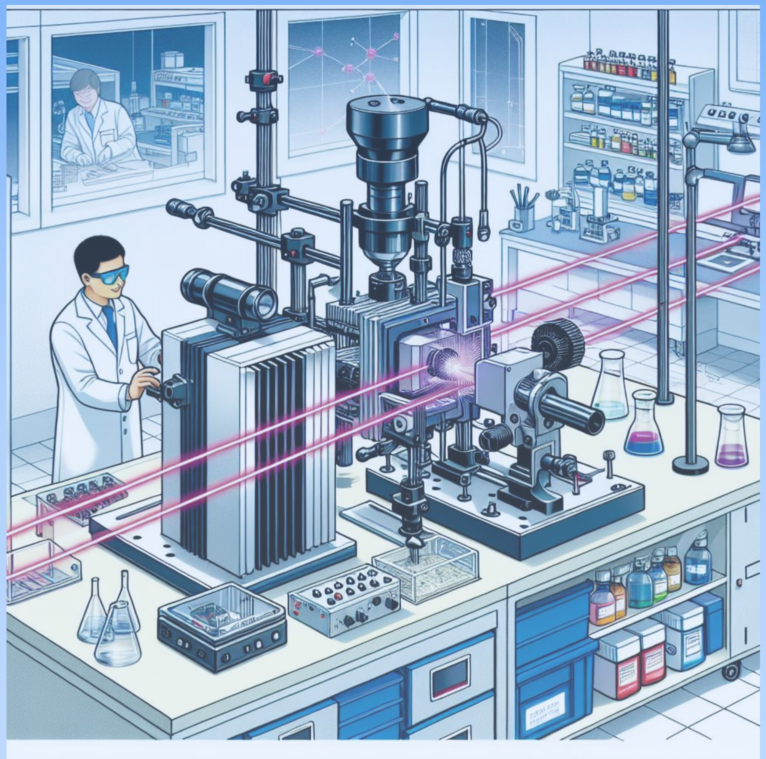
# A challenging project ….

- … but not ridiculously so
- The method could (should) be tested on (for example) stable Cs at some other facility
- This high-resolution method is absolutely not limited to Fr and Cs
- An important methodological development in its own right

# Practical issues:

When? After CERN shut-down period, work on proposal and test on other facility can (should) begin much earlier

Who? AK is willing to work on all parts of the project, but should not be PI; someone younger should be standard bearer



# Thanks for your attention!!